

## ABUNDANCE OF CETACEANS IN THE OCEANIC NORTHERN GULF OF MEXICO, 1996–2001

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### ABSTRACT

The Gulf of Mexico is a subtropical marginal sea of the western North Atlantic Ocean with a diverse cetacean community. Ship-based, line-transect abundance surveys were conducted in oceanic waters ( $>200$  m deep) of the northern Gulf within U.S. waters ( $380,432$  km<sup>2</sup>) during spring from 1996 to 1997 and from 1999 to 2001. Data from these five surveys were pooled and minimum abundance estimates were based on 12,162 km of effort and 512 sightings of at least 19 species. The most commonly sighted species (number of groups) were pantropical spotted dolphin, *Stenella attenuata* (164); sperm whale, *Physeter macrocephalus* (67); dwarf/pygmy sperm whale, *Kogia sima/breviceps* (58); Risso's dolphin, *Grampus griseus* (38); and bottlenose dolphin, *Tursiops truncatus* (24). The most abundant species (number of individuals; coefficient of variation) were *S. attenuata* (91,321; 0.16); Clymene dolphin, *S. clymene* (17,355; 0.65); spinner dolphin, *S. longirostris* (11,971; 0.71); and striped dolphin, *S. coeruleoalba* (6,505; 0.43). The only large whales sighted were *P. macrocephalus* (1,349; 0.23) and Bryde's whale, *Balaenoptera edeni* (40; 0.61). Abundances for other species or genera ranged from 95 to 2,388 animals. Cetaceans were sighted throughout the oceanic northern Gulf and, whereas many species were widely distributed, some had more regional distributions.

Key words: abundance, assessment, cetacean, Gulf of Mexico, line-transect, ship survey.

Tropical waters make up nearly one-half the area of the world's oceans (Longhurst and Pauly 1987), and about one-half the known cetacean species have tropical or broader distributions. Of these, approximately 31 species inhabit the open ocean and most ( $\sim 25$ ) are pantropical (Jefferson *et al.* 1993). However, relatively little is known about the ecology of pelagic tropical cetacean communities in most areas of the world. A major exception is the eastern tropical Pacific Ocean which has been intensively studied since the mid-1970s. Abundance surveys and a wide range of other studies have been conducted in the eastern tropical Pacific (*e.g.*, Au and Perryman 1985, Reilly 1990, Wade and Gerrodette 1993) because it is the site of mortality of spinner dolphins (*Stenella longirostris*) and pantropical spotted dolphins

(*S. attenuata*) (among other delphinids) associated with the yellowfin tuna (*Thunnus albacares*) purse-seine fishery.

Another exception is the Gulf of Mexico, a semi-enclosed subtropical marginal sea in the western North Atlantic Ocean covering an area over 1,500,000 km<sup>2</sup> with an average depth of 1,700 m (Gore 1992). There have been studies of cetaceans in the northern Gulf of Mexico since the mid-1970s that focused on continental shelf waters (e.g., Scott 1990), and studies of deeper waters were initiated in the late 1980s (e.g., Mullin *et al.* 1994). These studies indicate that northern Gulf of Mexico continental shelf waters (<200 m deep) are inhabited primarily by bottlenose dolphins (*Tursiops truncatus*) and Atlantic spotted dolphins (*S. frontalis*), while oceanic waters (>200 m deep) are routinely inhabited by at least 20 species, most of which have pantropical distributions (Mullin and Hansen 1999).

The impetus for cetacean research in northern Gulf waters has been the need to meet mandates of United States marine mammal protection legislation. Over 70% of the oil and natural gas deposits extracted from U.S. waters come from the northern Gulf of Mexico (Würsig *et al.* 2000) where there are nearly 4,000 oil and gas related platforms with about 500 in waters deeper than 200 m (U.S. Minerals Management Service, unpublished data). Other major human activities include shipping (almost 45% of U.S. tonnage) and fishing (Würsig *et al.* 2000). The Mississippi River, which drains about two-thirds of the continental U.S., flows into the north-central Gulf and deposits its nutrient load which is linked to the formation of one of the world's largest areas of seasonal hypoxia (Rabalais *et al.* 1999).

Estimating cetacean abundance for management has been the primary objective of the majority of surveys conducted in the Gulf of Mexico (e.g., Waring *et al.* 2001). Cetacean abundance estimates for northern continental shelf waters were reported by Fulling *et al.* (2003) and for northwestern continental slope waters by Jefferson (1996). However, abundance estimates for the expanse of northern Gulf of Mexico oceanic waters have been reported in U.S. government documents only (e.g., Hansen *et al.* 1995,<sup>1</sup> Mullin and Hoggard 2000, Waring *et al.* 2001).

In addition to being a key component of cetacean management, estimating the abundances of species and defining their distributions is a critical component in understanding how cetaceans function in tropical ecosystems. Ballance and Pitman (1998) compared cetacean communities from the eastern tropical Pacific, Gulf of Mexico, and western tropical Indian Ocean and found distinct differences between them; particularly in the relative abundances of species even though each is inhabited by the same core group of species. They suggested that more detailed comparisons could provide the basis for understanding the ecological mechanisms that shape tropical cetacean communities. Abundance of species is also an essential component of estimating cetacean biomass and prey requirements, and developing an understanding of the role of cetaceans in marine ecosystems (Hain *et al.* 1985, Katona and Whitehead 1988, Bowen 1997).

Our purpose here is to provide estimates of the abundance of cetacean species in the oceanic northern Gulf of Mexico based on ship surveys conducted from 1996 to

<sup>1</sup> Hansen, L. J., K. D. Mullin and C. L. Roden. 1995. Estimates of cetacean abundance in the northern Gulf of Mexico from vessel surveys. Southeast Fisheries Science Center Contribution No. MIA-94/5-25. 20 pp. Available from National Marine Fisheries Service, 3209 Frederic Street, Pascagoula, MS 39567.

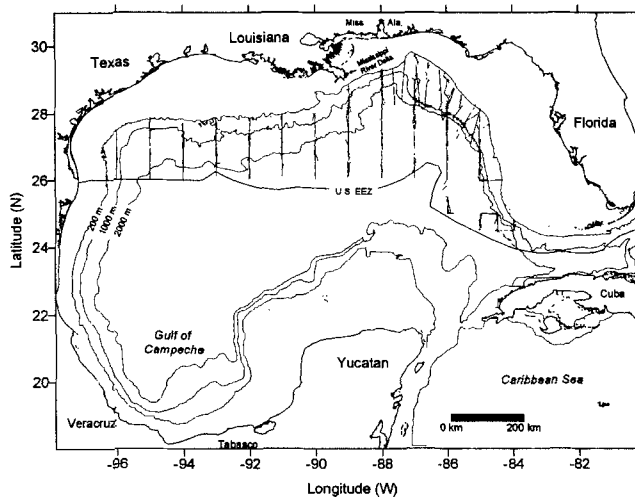


Figure 1. On-effort ship survey effort used to estimate abundances of cetaceans in the oceanic northern Gulf of Mexico during spring from 1996 to 2001.

2001. These cetacean abundance estimates are for one of the largest areas of tropical waters surveyed in the Atlantic Ocean.

## METHODS

### *Study Area*

The Gulf of Mexico (Gulf) is physiographically diverse and oceanographically complex. Continental shelves (waters <200 m deep) make up 36% of the total area (Baumgartner 1997). The continental shelves are generally wide (up to 200 km) in the northern Gulf and north of the Yucatan Peninsula, whereas they are much narrower near the Mississippi River Delta and in the southwestern Gulf (Fig. 1). Continental slopes (waters 200–2,000 m) comprise 26% of total Gulf area. Slope width is variable but is consistently broad off Louisiana and Texas and generally narrow in the southwestern Gulf. The slope is broad off Florida in waters 200–1,000 m deep but is narrow, becoming the West Florida Escarpment in waters 1,000–2,000 m deep. Slope topography is most diverse off the Yucatan Peninsula in the eastern Bay of Campeche (Gore 1992).

The mean state of Gulf oceanic waters is oligotrophic ( $<0.1$  mg chl/m<sup>3</sup>), but productivity is significantly enhanced in local areas by a variety of dynamic processes that are spatially and temporally variable (Biggs and Ressler 2001). The Loop Current (LC), the Gulf's dominant oceanographic feature, enters the Gulf between the Yucatan and Cuba, pushes variably north into the eastern Gulf, sometimes as far as the Mississippi-Alabama Shelf, circulates anticyclonically and exits through the Straits of Florida where it joins the Antillean Current to form the Gulf Stream. The LC periodically sheds anticyclonic (warm-core) eddies 200–300 km in diameter which drift slowly ( $\sim 5$  km/d) to the west and spin down as they interact with the continental slope in the western Gulf. Upwelling occurs along the

LC front and in cyclonic (cold-core) eddies that routinely form in association with the LC front or eddies. Nutrient-rich shelf waters are periodically entrained in the confluence of these cyclone/anticyclone pairs and transported to oceanic water. Nutrient-rich Mississippi River water is also variably entrained, and the river plume periodically extends across the narrow shelf into the oceanic north-central Gulf.

The study area (380,432 km<sup>2</sup>) was the oceanic waters ( $\geq 200$  m deep) of the northern (U.S.) Gulf west of 83°55' W, and generally north of a line between the U.S.-Mexico border and southern Florida (24.0°N). The study area comprised 35% of the oceanic Gulf (Fig. 1).

### Survey Design

Five annual spring surveys between 1996 and 2001 were conducted from the 52-m NOAA ship *Oregon II* (1996, 1997, 1999) and the 68-m NOAA ship *Gordon Gunter* (2000, 2001). The five surveys were  $\sim 44$  d in duration from mid-April to early June and were divided into two legs of  $\sim 22$  d each. In 1996 and 1997, surveys were also conducted in slope waters of the northeastern Gulf during a third 10-d leg. Standard visual line-transect survey methods for cetaceans similar to those used in the Pacific and other Gulf surveys were used (e.g., Wade and Gerrodette 1993, Barlow 1995, Hansen *et al.* 1995<sup>1</sup>). Bluefin tuna (*T. thynnus*) spawn during spring in the deep Gulf and surveys were conducted in conjunction with sampling for tuna ichthyoplankton along a predetermined trackline which uniformly covered the entire study area. The trackline was transited 24 h/d to accommodate plankton sampling at stations spaced 55.6 km (30 nmi) apart with cetacean surveys occurring during daylight hours (Fig. 1). The plankton stations in the far western Gulf were of lower priority. Therefore, in some cases, that area was not surveyed due to poor weather or mechanical problems with the ship.

Data were collected by two teams of three observers from the ship's flying bridge, located 9.2 m (*Oregon II*) or 14.5 m (*Gunter*) above the surface of the water, weather permitting (i.e., no rain, Beaufort sea state  $< 6$ ). Each team had at least two members experienced in shipboard line-transect methods and identification of tropical cetaceans. The left and right side observers searched out to the horizon in the arc from 10° right or left of the ship's bow to the left or right beam (90°), respectively, using 25 $\times$  binoculars. The third observer searched using unaided eye or 7 $\times$  hand-held binoculars and recorded data. Observers changed position every 30–40 min, and each team alternated 2-h watches throughout daylight hours. The survey speed was usually 18 km/h, but varied with sea conditions.

Data were recorded on a computer interfaced with a global positioning system (GPS) via a data acquisition program. Data collected for each cetacean sighting included time, position, bearing, and reticle (a measure of radial distance) of the sighting, species, group-size, behavior, bottom depth, sea-surface temperature, and associated animals (e.g., seabirds, fish). The bearing and radial distance for sightings made close to the ship by the data recorder were estimated. Survey effort data were automatically recorded every 2 min and included position, heading, effort status, observer position, and environmental conditions that could affect the observers' abilities to sight animals (e.g., Beaufort sea state, sun position).

Typically, if a sighting was within a 5.5-km strip on either side of the ship, the ship was diverted from the transect line, and the group approached so that observers

could identify species and obtain group-size estimates. For each sighting, the final group size was estimated by a consensus of the primary team.

Cetaceans were identified to the lowest taxonomic level possible based on descriptions in field guides and scientific literature (e.g., Jefferson *et al.* 1993) (Table 1). Short-finned pilot whales (*Globicephala macrorhynchus*) cannot be reliably distinguished at sea from long-finned pilot whales (*G. melas*). Both species occur in the North Atlantic, but only *G. macrorhynchus* are known to inhabit the Gulf (Jefferson 1995). Overall abundances for the genus *Kogia* and the genus *Mesoplodon* were estimated. Dwarf sperm whales (*K. sima*) and pygmy sperm whales (*K. breviceps*) were difficult to distinguish during the survey and stranding records of both species are common from the Gulf (Jefferson 1995). Stranding records of mesoplodont whales from the Gulf indicate *Mesoplodon* sightings were probably Gervais' (*M. europaeus*) or Blainville's (*M. densirostris*) beaked whales (Mead 1989). An observer's ability to make identifications depended on weather and animal behavior, and in some cases cetaceans could be identified only as unidentified Ziphiidae (Cuvier's beaked whale, *Ziphius cavirostris* or *Mesoplodon* sp.), large whale (>7 m long), small whale (non-dolphin, <7 m), dolphin, or odontocete.

#### Analytical Techniques

Because the distribution of survey effort was not uniformly or randomly distributed (Fig. 1), for abundance estimates, we delineated the effort into three strata (Table 2): abyssal (AB), waters >2,000 m deep to the boundary of the U.S. Exclusive Economic Zone (EEZ) (186,412 km<sup>2</sup>); northeast continental slope (NE), waters 200–2,000 m deep between 83°55.0' and 88°30.0' W (64,674 km<sup>2</sup>); and northwest continental slope (NW), waters 200–2,000 m deep west of 88°30.0' W (129,346 km<sup>2</sup>). We excluded survey effort from the analysis that was parallel to bathymetry gradients and that occurred in waters outside the study area or in a Beaufort sea state >4.

For each species, genus, or unidentified category (*i*) and stratum (*j*), abundance ( $N_{i,j}$ ) was estimated with line-transect methods using program DISTANCE (Laake *et al.* 1993, Buckland *et al.* 2001) and summed across strata for a total abundance by:

$$N_i = \sum_{j=1}^3 \frac{A_j \cdot n_{i,j} \cdot S_{i,j} \cdot f_i(0)}{2 \cdot L_j \cdot g(0)},$$

where  $A_j$  = area of stratum *j*,

$n_{i,j}$  = number of group sightings of species *i* in stratum *j*,

$S_{i,j}$  = mean group size of species *i* in stratum *j*,

$f_i(0)$  = sighting probability density function at perpendicular distance zero for species *i*,

$L_j$  = total length of transect line in stratum *j*, and

$g(0)$  = probability of seeing a group on the transect line.

Abundance estimates were negatively biased because observers, without doubt, missed groups on the transect line at the surface, and some groups were under the surface while in the observation area; therefore  $g(0) < 1$  (see Discussion). However, the parameter  $g(0)$  was not estimated and  $g(0) = 1$  was used for each abundance estimate. The log-normal 95% confidence interval was computed for each

Table 1. Estimate of  $f_i(0)$  for each species sighted  $\geq 30$  times and species categories. Species pooled to estimate  $f_i(0)$  for species categories (e.g., Large Whales) are listed ( $n$  = number of group sightings after truncation; ESW = effective half-strip width,  $1/f(0)$ ).

Species/species group	$n$	Truncation (m)	$f_i(0)$ ( $\text{km}^{-1}$ )	CV[ $f_i(0)$ ]	ESW (m)
<i>Stenella attenuata</i>	156	4,500	0.655	0.10	1,527
<i>Physeter macrocephalus</i>	67	5,500	0.570	0.13	1,755
<i>Kogia</i> spp.	58	4,000	0.467	0.06	2,143
<i>Grampus griseus</i>	38	4,000	0.535	0.17	1,869
Unidentified dolphin	36	4,500	0.359	0.11	2,782
Large Whales	77	5,500	0.523	0.13	1,913
<i>Physeter macrocephalus</i>					
<i>Balaenoptera edeni</i>					
Unidentified large whale					
Cryptic Whales	94	4,000	0.599	0.08	1,670
<i>Kogia</i> spp.					
<i>Ziphius cavirostris</i>					
<i>Mesoplodon</i> spp.					
Unidentified small whale					
Unidentified ziphiid					
Unidentified odontocete					
Small Whales/Large Dolphins	85	4,000	0.619	0.12	1,616
<i>Feresa attenuata</i>					
<i>Pseudorca crassidens</i>					
<i>Orcinus orca</i>					
<i>Globicephala macrorhynchus</i>					
<i>Tursiops truncatus</i>					
<i>Grampus griseus</i>					
<i>Stenella frontalis</i>					
<i>Steno bredanensis</i>					
Small Dolphins	206	4,500	0.643	0.08	1,555
<i>Peponocephala electra</i>					
<i>Lagenodelphis hosei</i>					
<i>Stenella longirostris</i>					
<i>Stenella attenuata</i>					
<i>Stenella clymene</i>					
<i>Stenella coeruleoalba</i>					
<i>Stenella</i> spp.					

abundance estimate because it was a product of estimates and tends to have a skewed distribution. The variance of  $N_{i,j}$  was estimated as

$$\text{var}(N_{i,j}) = N_{i,j}^2 \left( \frac{\text{var}(n_{i,j})}{n_{i,j}^2} + \frac{\text{var}(S_{i,j})}{S_{i,j}^2} + \frac{\text{var}[f_i(0)]}{f_i(0)^2} \right).$$

The sampling unit was the length of the transect completed in a stratum on-effort each day with Beaufort sea state  $\leq 4$ . The formula used to estimate each component of the variance followed Buckland *et al.* (2001).  $\text{Var}(n_{i,j})$  was length-weighted and

Table 2. Survey effort by stratum from spring 1996 to 2001 used to estimate the abundance of cetacean species in the oceanic northern Gulf of Mexico (Beaufort sea state  $\leq 4$ ; NE = Northeast Slope, 200–2,000 m, 88°30.0'–83°55.0'W; NW = Northwest Slope, 200–2,000 m, west of 88°30.0'W; AB = Abyssal region >2,000 m to U.S. EEZ).

Year	Abyssal (km)	NE Slope (km)	NW Slope (km)	Total (km)
1996	1,096	972	580	2,648
1997	1,163	1,130	642	2,935
1999	1,380	463	933	2,776
2000	1,071	383	381	1,835
2001	664	404	900	1,967
Total	5,374	3,353	3,436	12,162
Area (km <sup>2</sup> )	186,412	64,674	129,346	380,432

based on the variation in the number of on-effort group sightings between sampling units that ranged up to 168 km/d. Coefficient of variations were estimated as  $CV(N_{i,j}) = [\text{var}(N_{i,j})]^{1/2}/N_{i,j}$  and  $CV(N_i)$  as

$$CV(N_i) = \left[ \sum_{j=1}^3 CV^2(N_{i,j}) \cdot N_{i,j}^2 \right]^{1/2} / \sum_{j=1}^3 N_{i,j}.$$

For species sighted  $\geq 30$  times  $f_i(0)$  was estimated separately. Since the number of groups sighted of most species was insufficient to estimate  $f_i(0)$ , data from species with similar sighting characteristics (*i.e.*, body size, group-size, surface behavior, blow visibility) were pooled to estimate  $f_i(0)$  for four categories: Large Whales, Cryptic Whales, Small Whales/Large Dolphins, and Small Dolphins (Table 1). Data from species sighted  $\geq 30$  times were included in the pooled estimate of  $f_i(0)$  for the appropriate category.

The perpendicular distance,  $y$ , for each sighting was estimated using bearing and reticle measurements. The reticle readings were converted to radial sighting distances ( $R$ ) by the method of Lerczak and Hobbs (1998), using the formula  $y = R \sin(b)$ , where  $b$  = angle between the sighting and the transect line. Estimates of  $f_i(0)$  were made using a hazard-rate, uniform, or half-normal model with exact perpendicular sighting distances. Model selection was determined using Akaike's Information Criterion (AIC; Buckland *et al.* 2001).

Where abundance was estimated with a pooled  $f_i(0)$ , if the individual detection functions of each species within a category were indeed very similar, by pooling,  $\text{var}[f_i(0)]$  was probably underestimated, because  $\text{var}[f_i(0)]$  was based on an artificially high sample size. On the other hand, if the true detection functions of the species within a category are highly variable,  $\text{var}[f_i(0)]$  for an individual species may be overestimated.

The group sizes for some species tended to be related to  $y$ , because in many cases larger groups are easier to see than small groups with increasing  $y$ . In general, the arithmetic mean of group size may be an overestimate of the true mean group size and could lead to positively biased abundance estimates. Therefore, a regression of group size by  $y$  was used to estimate an "expected mean group size" (program DISTANCE). The expected mean group size was used in the abundance estimate

if it was significantly ( $P < 0.15$ ) smaller than the arithmetic mean group size.  $\text{Var}(S_{i,j})$  was the analytical variance for mean group sizes based on arithmetic means or was estimated as in Buckland *et al.* (2001) for expected mean group sizes.

One requirement for unbiased line-transect estimates of abundance is that the cetacean group should not move in response to the ship before it is sighted (Buckland *et al.* 2001). If cetaceans are not sighted before they respond to the ship, in cases of attraction to the ship,  $f(0)$  and abundance will be overestimated. During previous Gulf surveys, certain dolphin species (*e.g.*, *T. truncatus*; *Stenella* spp.; rough-toothed dolphin, *Steno bredanensis*) were consistently attracted to bowride as the ship approached (Würsig *et al.* 1998). Therefore, the abundance and variance of naked-eye sightings of these species were estimated separately, using the formulas above for the entire study area (*i.e.*, without area  $j$  stratification) with the exception that  $f_i(0)$  was treated as a constant. That is, they were estimated with strip-transect methods using a strip width equal to the line-transect effective strip half-width,  $1/f_i(0)$ , and  $\text{var}[1/f_i(0)] = 0$ .

## RESULTS

Annual survey effort ranged from 1,835 km to 2,935 km and total effort for the five surveys was 12,162 km. There was about twice as much effort per unit area in the NE Slope stratum ( $0.052 \text{ km/km}^2$ ) than in the NW Slope or Abyssal strata (Table 2). Estimates of  $f_i(0)$  ranged from  $0.359 \text{ km}^{-1}$  for unidentified dolphin to  $0.655 \text{ km}^{-1}$  for *S. attenuata* (Table 1).

Minimum abundance estimates were based on 512 sightings of at least 19 cetacean species (Table 3). The most commonly sighted species were *S. attenuata*; sperm whale, *Physeter macrocephalus*; *Kogia sima*/*breviceps*; Risso's dolphin, *Grampus griseus*; and *T. truncatus*. The most abundant species were *S. attenuata*; Clymene dolphin, *S. clymene*; *S. longirostris*; and striped dolphin, *S. coeruleoalba* (Table 3). The only large whales sighted were *P. macrocephalus* and Bryde's whales, *Balaenoptera edeni*. Abundances for other species or genera ranged from 95 to 2,388 animals.

The precision of the abundance estimates (expressed as CV) was quite variable among species and was primarily dependent on the number of sightings. For identified species or genera, the CV for overall estimates ranged from 0.16 to 0.49 for ten estimates and was  $>0.50$  for the other eight estimates. Because the precision of most of the regional (stratum) estimates was generally poor ( $>0.30$ ; Table 3), the power to detect statistically significant differences in estimates was low (Gerrodette 1987).

Cetaceans were sighted throughout the oceanic northern Gulf (Fig. 2) and some commonly sighted species such as *P. macrocephalus* (Fig. 3), *Kogia* spp., *G. griseus*, and *S. attenuata* (Fig. 4) were widely distributed. However, although based on a small number of group sightings, regional densities for some of these widely distributed species appear dissimilar (Table 3). The density of *P. macrocephalus* was lower in the NE Slope stratum than in the other two strata, while that of *S. attenuata* was lowest in the NW Slope stratum. *G. griseus* densities were higher in slope strata.

Other species were less broadly distributed. *T. truncatus* was encountered primarily in upper continental slope waters  $<1,000 \text{ m}$  deep (Fig. 5) and had the highest densities in the NE Slope. Eleven of 12 *S. longirostris* sightings and all *B. ednei* sightings were in the NE Slope (Fig. 5). False killer whales (*Pseudorca*

Table 3. Group-size, density and abundance estimates of cetaceans in northern Gulf of Mexico oceanic waters (200 m—seaward boundary of the U.S. EEZ; NE = Northeast Slope, NW = Northwest Slope, AB = Abyssal,  $n$  = number of groups sighted,  $S$  = mean group size,  $D$  = animals  $\cdot$  100 km<sup>-2</sup>,  $N$  = number of animals, CV = coefficient of variation).

Species/stratum	$n$	$S$	CV( $S$ )	$D$	$N$	CV( $N$ )	95% CI
<i>Balaenoptera edeni</i>							
NE	4	2.0	0.35	0.06	40	0.61	13–129
NW	0	—	—	0	0	—	—
AB	0	—	—	0	0	—	—
TOTAL	4			0.01	40	0.61	13–129
<i>Physeter macrocephalus</i>							
NE	7	2.6	0.22	0.15	99	0.46	42–236
NW	29	1.8	0.12	0.43	558	0.37	275–1,131
AB	31	2.3	0.13	0.37	692	0.32	373–1,283
TOTAL	67			0.35	1,349	0.23	869–2,093
<i>Kogia</i> spp.							
NE	16	1.4	0.11	0.15	99	0.38	48–204
NW	13	2.2	0.16	0.20	255	0.49	100–650
AB	29	1.7	0.09	0.21	388	0.44	168–896
TOTAL	58			0.20	742	0.29	425–1,294
<i>Ziphius cavirostris</i>							
NE	2	2.5	0.20	0.04	29	0.64	9–94
NW	1	4.0	—	0.03	45	0.82	11–191
AB	2	1.0	0	0.01	21	0.75	6–78
TOTAL	5			0.02	95	0.47	40–226
<i>Mesoplodon</i> spp.							
NE	1	3.0	—	0.03	17	1.15	3–109
NW	5	1.2	0.17	0.05	68	0.54	25–186
AB	2	1.0	0	0.01	21	0.58	7–61
TOTAL	8			0.03	106	0.41	49–229
Unidentified ziphiid							
NE	0	—	—	0	0	—	—
NW	1	1.0	—	<0.01	11	0.60	4–34
AB	6	2.2	0.30	0.07	135	0.49	52–350
TOTAL	7			0.04	146	0.46	62–342
<i>Feresa attenuata</i>							
NE	0	—	—	0	0	—	—
NW	0	—	—	0	0	—	—
AB	4	9.5	0.28	0.22	408	0.60	134–1,244
TOTAL	4			0.11	408	0.60	134–1,244
<i>Pseudorca crassidens</i>							
NE	2	28.5	0.23	0.53	340	0.65	102–1,136
NW	0	—	—	0	0	—	—
AB	1	65.0	—	0.37	698	1.00	134–3,630
TOTAL	3			0.27	1,038	0.71	299–3,607

Table 3. Continued.

Species/stratum	<i>n</i>	<i>S</i>	CV( <i>S</i> )	<i>D</i>	<i>N</i>	CV( <i>N</i> )	95% CI
<i>Orcinus orca</i>							
NE	0	—	—	0	0	—	—
NW	2	2.0	0	0.04	47	0.67	14–157
AB	3	2.7	0.33	0.05	86	0.66	25–296
TOTAL	5			0.03	133	0.49	54–329
<i>Globicephala</i> sp.							
NE	0	—	—	0	0	—	—
NW	6	34.2	0.32	1.85	2,388	0.48	927–6,150
AB	0	—	—	0	0	—	—
TOTAL	6			0.63	2,388	0.48	927–6,150
<i>Peponocephala electra</i>							
NE	0	—	—	0	0	—	—
NW	3	95.0	0.17	2.67	3,451	0.55	1,237–9,627
AB	0	—	—	0	0	—	—
TOTAL	3			0.91	3,451	0.55	1,237–9,627
<i>Grampus griseus</i>							
NE	17	6.3	0.17	0.85	552	0.36	279–1,092
NW	10	8.1	0.21	0.63	816	0.47	335–1,987
AB	11	7.8	0.27	0.43	801	0.66	246–2,606
TOTAL	38			0.57	2,169	0.32	1,188–3,962
<i>Tursiops truncatus</i>							
NE	19	16.7	0.38	2.94	1,899	0.46	780–4,623
NW	4	5.6	0.84	0.25	263	0.95	20–3,380
AB	0	—	—	0	0	—	—
Strip–transect	1	8.0	—	0.02	77	0.99	15–391
TOTAL	24			0.59	2,239	0.41	1,039–4,825
<i>Steno bredanensis</i>							
NE	3	8.7	0.55	0.24	155	0.82	30–791
NW	1	15.0	—	0.14	175	1.04	31–975
AB	1	25.0	—	0.14	268	0.84	63–1,150
Strip–transect	3	13.3	0.63	0.10	387	0.77	67–2,231
TOTAL	8			0.26	985	0.44	431–2,251
<i>Lagenodelphis hovei</i>							
NE	1	117.0	—	1.12	726	0.70	206–2,556
NW	0	—	—	0	0	—	—
AB	0	—	—	0	0	—	—
TOTAL	1			0.19	726	0.70	206–2,556
<i>Stenella frontalis</i>							
NE	0	—	—	0	0	—	—
NW	1	15.0	—	0.14	175	0.84	41–752
AB	0	—	—	0	0	—	—
TOTAL	1			0.05	175	0.84	41–752
<i>Stenella longirostris</i>							
NE	11	164.0	0.69	17.30	11,190	0.76	2,616–47,864
NW	0	—	—	0	0	—	—
AB	1	70.0	—	0.42	781	0.64	243–2,508
TOTAL	12			3.15	11,971	0.71	3,414–41,977

Table 3. Continued.

Species/stratum	<i>n</i>	<i>S</i>	CV( <i>S</i> )	<i>D</i>	<i>N</i>	CV( <i>N</i> )	95% CI
<i>Stenella attenuata</i>							
NE	44	57.8	0.16	24.82	16,053	0.28	9,386–27,457
NW	34	41.7	0.18	13.51	17,477	0.40	8,141–37,519
AB	78	62.8	0.13	29.83	55,609	0.21	37,294–82,917
Strip–transect	8	26.6	0.36	0.57	2,182	0.36	1,109–4,291
TOTAL	164			24.00	91,321	0.16	67,233–124,039
<i>Stenella clymene</i>							
NE	0	—	—	0	0	—	—
NW	8	64.3	0.28	4.28	6,228	0.73	1,694–22,906
AB	8	121.9	0.28	5.83	10,876	0.94	2,249–52,585
Strip–transect	1	12.5	0.20	0.07	251	0.61	82–769
TOTAL	17			4.56	17,355	0.65	5,464–55,120
<i>Stenella coeruleoalba</i>							
NE	4	21.3	0.41	0.82	527	0.65	15–1,843
NW	5	53.6	0.48	2.51	3,245	0.67	881–11,957
AB	3	81.7	0.08	1.47	2,733	0.62	883–8,456
TOTAL	12			1.71	6,505	0.43	2,917–14,508
<i>Stenella</i> spp.							
NE	2	6.0	0.33	0.12	74	0.34	19–294
NW	1	15.0	—	0.14	182	1.04	33–1,009
AB	3	10.7	0.63	0.19	357	0.90	61–2,106
Strip–transect	1	3.0	—	0.01	30	0.75	8–112
TOTAL	7			0.17	643	0.58	223–1,854
Unidentified dolphin							
NE	11	3.4	0.38	0.20	130	0.51	49–347
NW	5	7.7	0.82	0.20	260	0.99	37–1,846
AB	20	5.1	0.26	0.34	630	0.36	311–1,275
TOTAL	36			0.27	1,020	0.34	531–1,959
Unidentified small whale							
NE	0	—	—	0	0	—	—
NW	3	1.7	0.40	0.04	56	0.95	11–287
AB	5	1.0	0	0.03	52	0.48	21–129
TOTAL	8			0.03	108	0.54	40–293
Unidentified large whale							
NE	3	1.0	0	0.02	15	0.54	6–41
NW	0	—	—	—	0	—	—
AB	3	1.7	0.20	0.02	45	0.55	16–127
TOTAL	6			0.02	60	0.43	27–135
Unidentified odontocete							
NE	1	1.0	—	<0.01	6	0.61	2–18
NW	4	1.8	0.27	0.06	79	0.57	27–233
AB	3	1.7	0.40	0.03	52	0.63	15–182
TOTAL	8			0.04	136	0.41	64–295

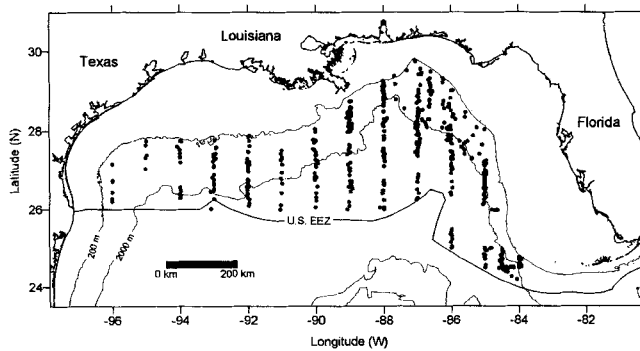


Figure 2. Locations of all cetacean groups ( $n = 512$ ) used to estimate abundance.

*crassidens*) were sighted only to the east of Mobile Bay, Alabama ( $\sim 88.0^\circ\text{W}$ ). Conversely, *G. macrorhynchus*, melon-headed whales (*Peponocephala electra*), *S. clymene*, and killer whales (*Orcinus orca*) were sighted primarily west of Mobile Bay (Fig. 5).

#### DISCUSSION

Most of the cetacean species found in the oceanic Gulf occur in deep, warm temperate to tropical waters throughout the world (Jefferson *et al.* 1993, Mullin and Hansen 1999). Only *S. clymene* and *S. frontalis* are restricted to the Atlantic. There are seven species with a small number of stranding and sighting records from the Gulf that were not sighted during the 1996–2001 surveys and are probably extralimital, strays from migration, or occasional migrants. These species are the blue whale (*B. musculus*), northern right whale (*Eubalaena glacialis*), Sowerby's beaked whale (*M. bidens*), humpback whale (*Megaptera novaeangliae*), fin whale (*B. physalus*), sei whale (*B. borealis*), and minke whale (*B. acutorostrata*) (Würsig *et al.* 2000). Common dolphins (*Delphinus* spp.) have been previously reported from the Gulf (*e.g.*, Caldwell 1955), however, all the available specimen records are *Stenella* that were misidentified, and sighting records were likely misidentified *S. clymene* (Jefferson and Schiro 1997). In the eastern tropical Pacific, where *D. delphis* are abundant, they are found associated in large areas (relative to the northern Gulf)

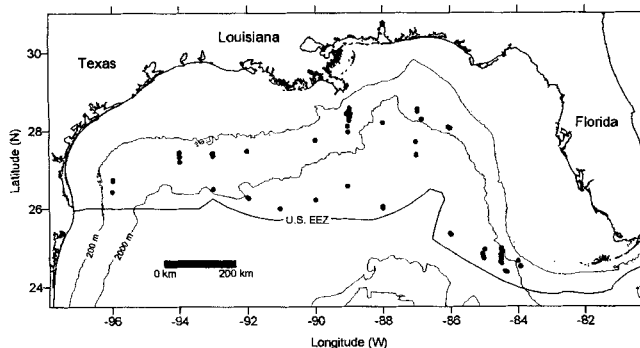


Figure 3. Locations of groups of *P. macrocephalus* ( $n = 67$ ) used to estimate abundance.

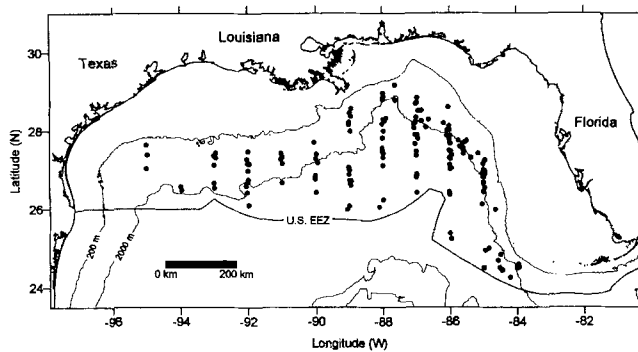


Figure 4. Locations of groups of *S. attenuata* ( $n = 164$ ) used to estimate abundance.

with upwelling modified waters with highly variable surface conditions (Au and Perryman 1985, Reilly 1990)—conditions that do not routinely occur in the Gulf or do not occur on a similar scale (Biggs and Reesler 2001).

The number of sightings for most species was too small from each survey to estimate abundance with reasonable precision, and our estimates are an effort-weighted average from five surveys over six years. Over six years, populations can grow or decline, or there can be changes in an ecosystem that could lead to significant shifts in distribution. Since these factors could confound our estimates, they should not be viewed as the state of the Gulf at any specific time. Ideally, abundance estimates would be based on surveys conducted over a short time with sufficient effort to yield large enough samples for precise estimates of each species. However, ship time is limited and expensive, and we took advantage of the survey opportunity afforded to us. Some Gulf species such as Fraser's dolphin (*Lagenodelphis hoesei*) are rare or uncommon and were not sighted during each survey year; we think these species were present, but that the effort was not sufficient to ensure sighting them.

*S. attenuata* was the only species with a relatively large number of sightings during each survey year. We estimated abundance for *S. attenuata* based on each survey with the following results: 1996—132,360 ( $CV = 0.28$ ); 1997—35,494

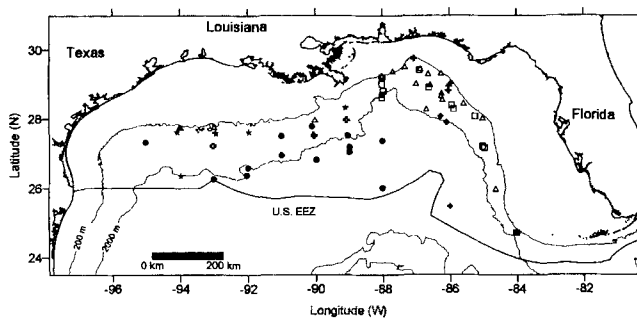


Figure 5. Locations of groups of *T. truncatus* ( $n = 24$ , triangle), *G. macrorhynchus* ( $n = 6$ , star), *P. electra* ( $n = 3$ , open cross), *P. crassidens* ( $n = 3$ , closed diamond), *S. clymene* ( $n = 17$ , circle), *S. longirostris* ( $n = 12$ , square), and *B. edeni* ( $n = 4$ , closed cross) used to estimate abundance.

(0.28); 1999—83,087 (0.33); 2000—134,420 (0.29); and 2001—86,574 (0.48). The reasons for these large intersurvey differences is certainly due to both sampling and oceanographic variability. Productivity in the oceanic Gulf, which ultimately affects the distribution of apex predators, is highly variable both spatially and temporally (Biggs and Ressler 2001). Wade and Gerrodette (1993) estimated cetacean abundances for the eastern tropical Pacific based on pooled data from annual surveys conducted over five years, but Wade and Gerrodette (1992) reported interannual variability in abundances from the same surveys that was similar to or greater than ours. Reilly and Fiedler (1994) found that interannual variability of dolphin habitats in the eastern tropical Pacific could account for much of the variability in the occurrence of certain species. Similar work with oceanographic data collected during the Gulf surveys needs to be performed.

Hansen *et al.* (1995)<sup>1</sup> reported the only previous abundance estimates of cetaceans for the entire oceanic northern Gulf. Data for these estimates were collected from 1991 to 1994 during annual spring surveys along the same ichthyoplankton cruise track and during dedicated surveys of the northwestern Gulf. Most abundances of species reported by Hansen *et al.* (1995)<sup>1</sup> were similar to our estimates and had similar precision that was generally poor. However, the 1991–1994 estimates for *S. frontalis* and *S. attenuata* were significantly different compared to ours ( $P < 0.05$ ) when tested using the methods described by Lo (1994) (see Forney and Barlow 1998). The 1991–1994 estimate for *S. frontalis* was 3,213 dolphins (CV = 0.44), which was more than 18 times larger than our estimate of 175 (0.84). However, the estimates by Hansen *et al.* (1995)<sup>1</sup> were based on a study area that included waters 100–200 m deep. This difference is critical because *S. frontalis* primarily inhabit the continental shelf in the Gulf where they are widely distributed and abundant (Fulling *et al.* 2003).

Our estimate of the abundance of *S. attenuata* (91,321; 0.16) for 1996–2001 was almost three times the 31,320 (0.20) estimated by Hansen *et al.* (1995)<sup>1</sup> for 1991–1994. Because the analytical methods were somewhat different, we estimated the abundance of *S. attenuata* from the 1991–1994 data with the same analytical protocols used here. The new estimate was larger (40,893; 0.19) but remained significantly different from the current estimate ( $P < 0.05$ ).

Our abundance estimates were based on surveys confined to the northern Gulf and it is difficult to interpret the significance of changes in cetacean abundance without a Gulf-wide perspective. Oceanic cetaceans are highly mobile and shifts in distribution on the small scale of the oceanic Gulf (maximum distance ~1,450 km) probably occur in response to changing oceanographic conditions. In the eastern tropical Pacific, groups of *S. attenuata* were found to travel an average net distance of 30–50 nmi (55–90 km) per day and may range over several hundred nautical miles (Perrin and Hohn 1994).

Abundance estimates of four species by Jefferson (1996) for the continental slope (200–2,000 m) in the northwestern Gulf were based on 1992–1993 ship surveys using similar methods and can be compared to our estimates from the NW Slope (Table 3). Estimates for *T. truncatus* and *P. macrocephalus* were very similar in both studies but our estimates for *S. clymene* and *S. attenuata* were 2–3 times larger.

Seasonal aerial surveys of continental slope waters in the northwestern Gulf from 1992 to 1994 (summer, fall, winter, spring) (Mullin *et al.* 2004) and in the northeastern Gulf from 1996 to 1998 (summer, winter) (Mullin and Hoggard 2000) provided some evidence of seasonal changes in species abundance in slope waters. For example, in the northeastern Gulf, *G. griseus* was three times more

abundant in winter compared to summer and *S. attenuata* was two times more abundant in summer. While the seasonal abundance results of these studies are not definitive, they showed that cetaceans remained diverse and abundant throughout the year, and no common species vacated slope waters seasonally.

The surveys were designed to meet the assumptions of line-transect theory (Buckland *et al.* 2001). However, our abundance estimates are negatively biased because the central assumption, that all cetacean groups on the transect line are detected (*i.e.*,  $g(0) = 1$ ), was certainly not met, and data were not collected to correct estimates for perception and availability bias (Marsh and Sinclair 1989). Barlow (1995) estimated perception bias for a ship survey in the Pacific and found that the majority of groups missed by the primary team were apparently small groups, although the group-sizes were not estimated at close range. He estimated  $g(0)$  ranging from 0.73 to 0.79 for small groups of delphinids (<21 animals). Perception bias varies by species because of, among other factors, differences in animal size, surface behavior, and group-sizes. Sea state also affects perception bias (Buckland *et al.* 2001), and, ideally, abundance estimates would be based on effort conducted in seas with very little swell and few whitecaps (Beaufort sea state 0–2). However, nearly 70% of the survey effort occurred in Beaufort sea states 3–4 and retaining effort in these suboptimal conditions (for some species or group-sizes) was a compromise between accuracy and precision.

Availability bias also varies by species, group-sizes, group diving behavior, and dive cycles. Long-diving *P. macrocephalus* and ziphiids will be at the surface much less than many small delphinids which have much shorter dive-cycles. Diving synchrony among members of a group also affects availability bias; if dives are asynchronous, the probability that at least one animal will be at the surface increases with group-size.

Barlow (1999) estimated both availability and perception bias for long-diving whales during ship surveys using 25× binoculars in a simulation study, and estimated that for *Kogia* spp., *Z. cavirostris*, and *Mesoplodon* spp., abundance estimates need to be increased two to four times (*i.e.*,  $g(0) = 0.50$  to  $g(0) = 0.25$ ) to account for these biases. Barlow's (1999) estimates of  $g(0)$  for perception and/or availability bias are probably representative of the bias in the Gulf survey because similar ship survey methods were used. However, it may not be valid to apply them directly to our abundance estimates because cetacean diving behavior and group-sizes may be temporally and geographically specific, and survey conditions and observers vary among surveys.

Except for the NE Slope surveys in 1996 and 1997, the surveys were conducted in conjunction with a long-term, bluefin tuna, ichthyoplankton sampling cruise with fixed sampling stations. The resulting cruise trackline pattern was not ideal for sampling the extreme western Gulf (west of ~94.0°W) and eastern Gulf south of Tampa Bay, Florida (~28.0°N). In those areas the transect lines tended to run parallel to the bathymetry gradient. Ideally, the transect lines would be randomly located or uniform from a random start each year, and cross bathymetry gradients in both cases. The fixed transect lines located ~100 km apart could have caused positive or negative bias if a species was aggregated at the same points year-to-year at a smaller spatial scale. That is, positive bias if the transect lines crossed the aggregations or negatively biased if it constantly missed them. Results of seasonal aerial surveys of the continental slope in the northern Gulf with transect lines spaced 13.5 km apart do not indicate that any species, except perhaps *P. macrocephalus*, aggregates consistently in relatively small areas (Mullin and

Hoggard 2000, Mullin *et al.* 2004). During aerial surveys *P. macrocephalus* was consistently sighted near the Mississippi River Delta, but the area of concentration was >100 km wide.

Unidentified cetaceans also contributed to the negative bias of our abundance estimates (Table 3). Most dolphin species in the Gulf do not avoid ships (Würsig *et al.* 1998), and the abundance of unidentified dolphins was not large compared to the abundance estimates of most dolphin species. However, the bias would be of greater significance if the unidentified groups were primarily of one or two species. There were 36 dolphin groups which were unidentified because they were usually sighted at a large radial distance and could not be relocated. The average group-size of these groups was small (<8). However, when groups are approached, typically group-size estimates are larger than observers' initial impression, so this bias is probably underestimated. Unidentified small whales were most likely *Kogia* spp. and ziphiids because their small group-sizes and cryptic behavior make them difficult to observe for long periods of time or at close range. Unidentified large whales are more problematic. *B. edeni*, *P. macrocephalus*, and *O. orca* are the only cetaceans that typically occur in the Gulf that meet our definition, *i.e.*, are usually >7 m long. The former two have distinctive blows, and *O. orca* has distinct coloration and dorsal fin, so these species should be identifiable in good conditions.

For our estimates, we assumed that with the 25× binoculars cetacean groups were sighted before they were attracted to the ship or avoided it. These behaviors could have biased our estimates of  $f(0)$  and density if consistently displayed by a species before it was sighted (Buckland *et al.* 2001). Our experience, while not quantified, is that species that appear to avoid the ship such as *Kogia* spp. and ziphiids, simply dive, and that species that swim away, such as *G. griseus* and *S. attenuata*, only do so when the ship is close (<1 km). As stated before, it is clear some delphinid species are attracted to the ship to ride the bow. However, 82% of the 25× binocular sighting were made at radial (line-of-sight) distances of >2 km, and cetaceans do not appear to be responding to the ship at those distances.

The general distribution tendencies for species conveyed by our stratum density estimates (Table 3) were similar to those from previous northern Gulf ship or aerial surveys (Hansen *et al.* 1995,<sup>1</sup> Hansen *et al.* 1996, Jefferson 1996, Mullin and Hoggard 2000). However, most oceanic species not sighted in a stratum during spring from 1996 to 2001 were sighted at least once in that stratum during previous surveys.

Both *T. truncatus* and *S. frontalis* are abundant in northern Gulf continental shelf waters (Fulling *et al.* 2003). In Gulf oceanic waters, *S. frontalis* usually occur near the shelf-edge in waters <500 m deep (Davis *et al.* 1998). The smaller "offshore" form of *S. frontalis*, that occurs far from the shelf-edge in parts of the oceanic North Atlantic (Perrin 2002, Mullin and Fulling 2003), has not been recorded from the northern Gulf. Both the "coastal" and "offshore" ecotypes of *T. truncatus* (Hersh and Duffield 1990) occur in the Gulf (LeDuc and Curry 1998). How these ecotypes are distributed in the northern Gulf and western North Atlantic is being investigated with skin biopsy samples collected, in part, during the 1991–2001 oceanic surveys (*e.g.*, Curry and Smith 1997). Using *T. truncatus* mitochondrial DNA from the western North Atlantic, Torres *et al.* (2003) reported that all samples from beyond 34 km from shore and deeper than 34 m were the offshore ecotype. If this is also the case for the northern Gulf, all *T. truncatus* in oceanic waters are the offshore ecotype.

Groups of *T. truncatus* were generally confined to the shelf-edge except in the NE Slope region where their distribution extended well seaward of the shelf-edge (Fig.

5). In the eastern Gulf the continental slope is very broad in waters 200–1,000 m deep, but forms the West Florida Escarpment in waters 1,000–2,000 m deep (Fig. 1). The distribution of *T. truncatus* is similar in the U.S. North Atlantic where they are seldom sighted beyond continental shelf and slope waters (Kenney 1990, Mullin and Fulling 2003). In contrast, *T. truncatus* is distributed throughout oceanic areas in the eastern tropical Pacific (Scott and Chivers 1990, Wade and Gerrodette 1993).

Cetacean sighting and oceanographic data collected, in part, during the 1991–1994 (Hansen *et al.* 1995)<sup>1</sup> and/or 1996–1997 SEFSC surveys, have been used in conjunction with remote sensing (*e.g.*, sea-surface altimetry and AVHRR), physiographical data, and biological data to study cetacean habitats in the Gulf (Baumgartner 1997, Davis *et al.* 1998, Baumgartner *et al.* 2001, Davis *et al.* 2002). Although the abundances of some species may have changed since the earlier studies, the distribution of sightings of species we report here (Fig. 2–5) appear similar to those examined in Gulf habitat studies. The habitat studies have shown consistent relationships between static features in the Gulf (*e.g.*, water depth, bottom gradient, longitude) and the distributions of some species, but, for the most part, have not revealed consistent relationships to dynamic features (*e.g.*, sea-surface temperature, LC eddies, anticyclonic eddies, plankton biomass, Mississippi River discharge). The habitat studies discuss in detail how dynamic features may ultimately affect the distributions of the abundant species. For example, *P. macrocephalus* occur throughout northern Gulf oceanic waters (Fig. 3), but there is consistently one aggregation of sightings just off the Mississippi River Delta and another in the southeastern Gulf west of the Dry Tortugas (~25°N, 84°W). These aggregations, respectively, are thought to result from primary productivity associated with the Mississippi River plume, which is the highest recorded in the Gulf (Lohrenz *et al.* 1999), and productivity that is enhanced by nutrient upwelling associated with the LC front and the periodic formation of the cyclonic Tortugas Gyre in the southeastern Gulf (Lee *et al.* 1994, Wiseman and Sturges 1999).

Our estimates indicate that *S. attenuata* is by far the most abundant species in the oceanic northern Gulf and makes up about 63% of all cetaceans. However, the number of individuals may not be the best indicator of the ecological importance or impact of a species in an ecosystem. Mullin and Hansen (1999), using methods outlined by Hain *et al.* (1985), estimated about 1% of the cetaceans in the oceanic northern Gulf are *P. macrocephalus*, but this species makes up about 60% of the cetacean biomass.

Sixty-five percent of Gulf oceanic waters are south of the U.S. EEZ where cetacean abundance has not been assessed. Ortega-Ortiz (2002) summarized cetacean sightings in Mexican waters of the southern Gulf. Species composition and distributions appear similar to that in the northern Gulf; *T. truncatus* and *S. frontalis* occurred primarily in shelf waters and other species in oceanic waters. It is important to study cetacean abundance and distribution from a Gulf-wide perspective for both cetacean management and basic understanding of the Gulf ecosystem.

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